LCA Case Studies

Environmental Assessment of Energy Production from Municipal Solid Waste Incineration

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Abstract

Background, Aims and Scope. During the combustion of municipal solid waste (MSW), energy is produced which can be utilized to generate electricity. However, electricity production from incineration has to be evaluated from the point view of the environmental performance. In this study, environmental impacts of electricity production from waste incineration plant in Thailand are compared with those from Thai conventional power plants.

Methods. The evaluation is based on a life cycle perspective using life cycle assessment (LCA) as the evaluation tool. Since MSW incineration provides two services, viz., waste management and electricity production, the conventional power production system is expanded to include landfilling without energy recovery, which is the most commonly used waste management system in Thailand, to provide the equivalent function of waste management.

Results. The study shows that the incineration performs better than conventional power plants vis-à-vis global warming and photochemical ozone formation, but not for acidification and nutrient enrichment.

Discussion. There are some aspects which may influence this result. If landfilling with gas collection and flaring systems is included in the analysis along with conventional power production instead of landfilling without energy recovery, the expanded system could become more favorable than the incineration in the global warming point of view. In addition, if the installation of deNO$_x$ process is employed in the MSW incineration process, nitrogen dioxide can be reduced with a consequent reduction of acidification and nutrient enrichment potentials. However, the conventional power plants still have lower acidification and nutrient enrichment potentials.

Conclusions. The study shows that incineration could not play the major role for electricity production, but in addition to being a waste management option, could be considered as a complement to conventional power production. To promote incineration as a benign waste management option, appropriate deNO$_x$ and dioxin removal processes should be provided. Separation of high moisture content waste fractions from the waste to be incinerated and improvement of the operation efficiency of the incineration plant must be considered to improve the environmental performance of MSW incineration.

Recommendations. This study provides an overall picture and impacts, and hence, can support a decision-making process for implementation of MSW incineration. The results obtained in this study could provide valuable information to implement incineration. But it should be noted that the results show the characteristics only from some viewpoints.

Outlook. Further analysis is required to evaluate the electricity production of the incineration plant from other environmental aspects such as toxicity and land-use.

Keywords: Combustion of MSW; electricity production; energy production; land filling; land-use; life cycle assessment (LCA); MSW incineration; municipal solid waste (MSW); power plant; Thailand; toxicity, incineration

Introduction

In recent years, much emphasis has been placed on sustainable municipal solid waste (MSW) management. Incineration of waste with energy recovery is one of the interesting options. A large portion of the waste has significant energy potential which should be utilized [1–2]. The energy recovered can also reduce emissions that would otherwise be produced by other energy systems such as fossil-fired power plants [2–5].

The old practice of waste disposal has been to dump in open landfills, which results in *garbage* in and garbage remains. The goal for the new millennium must be garbage in and energy out in an environmentally acceptable manner [1]. The primary function of incineration is volume reduction and mineralization of the waste by thermal destruction. The recovery of energy for power production has been a secondary, but increasingly important function. However, the environmental implications of incineration with energy recovery should be assessed.

This study intends to evaluate whether electricity production from waste is really advantageous for the environment as is sometimes summarily assumed without rigorous analysis. Phuket, a province in the southern part of Thailand, is selected as the study site. Environmental impacts of electricity production from MSW incineration plant in Phuket are compared with those from conventional power plants in Thailand using life cycle assessment (LCA) as the evaluation tool.

LCA is a technique for assessing the environmental aspects and potential impacts associated with a product (or service), by compiling an inventory of relevant inputs and outputs of the product system; evaluating the potential environment impacts associated with those inputs and outputs; and interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study [6].

LCA considers the entire life cycle of products or services – from cradle to grave (from raw material acquisition through production, use, and disposal). It is thus a holistic assessment methodology of products or services. LCA has been proven to be a valuable tool to document the environmental considerations that need to be part of decision making towards environmental sustainability [7,8]. With a life cycle

perspective consideration, LCA avoids problem shifting in which an apparent improvement in one part of a life cycle can merely lead to further problems at another time or place [9]. However, the disposal phase in LCA is often neglected or indicated as kilogram waste. It is proved in [10] that the disposal phase should be included in LCA studies. The risk of decisions shifting burdens from the production or use phase to the disposal phase because of data gaps can therefore be diminished.

LCA has been successfully utilized in the field of solid waste management, for example, to assess differences in environmental performance between different waste incineration strategies [11] or related activities such as flue gas cleaning process of MSW incinerators [12], to compare the environmental performance of different scenarios for management of mixed solid waste as well as of specific waste fractions [3–5,13–16].

However, there have not been many studies comparing MSW management system producing energy with conventional (fossil) energy sources except for one study comparing emissions from coal combustion and MSW combustion [17]. However, that study was not based on a life cycle perspective and compared only gaseous emissions.

This study assesses the environmental loads of electricity production from MSW incineration in a life cycle perspective using conventional power production as the baseline. The objective is to assess the environmental performance of energy from MSW incineration and suggest measures for improvement.

1 Description of the Study Site

Phuket is an island province in the south of Thailand. It stretches 49 km from north to south and 19 km from east to west with the total area of 570 sq.km. With beautiful beaches along the western and southern parts of the island, Phuket is a major tourist attraction.

1.1 Current Phuket MSW management

MSW in Phuket is collected and transported by trucks to the treatment and disposal center. It is weighed and instantly separated based on source and characteristics of the waste to be managed by three methods – incineration, recycling and landfilling. Flow of current Phuket MSW in one year period (July 2003 to June 2004) is illustrated in **Fig. 1**. From Fig. 1 it can be seen that of the total MSW collected, an estimated 71% is sent to the incinerator, 26% landfilled, and 3% sorted and recovered for recycling.

1.2 Phuket incineration plant

Among the three methods, incineration is used as the main process to treat MSW and also provides electricity as a supplementary function. In this study, as the focus is on the electricity production from incineration, the details of the incineration are considered.

The incineration plant was completed in May 1998 and started operating in June 1999. The building is made of reinforced concrete and steel. The incinerator is of continuous burning grate-type with a capacity of 250 tonne MSW/day. The operation of the plant is controlled and monitored from a centralized computer room. For air pollution control, the plant is equipped with a unit consisting of dry scrubber using lime and bag filter and continuous emission monitoring equipment. Leachate from the refuse pit where MSW is stored

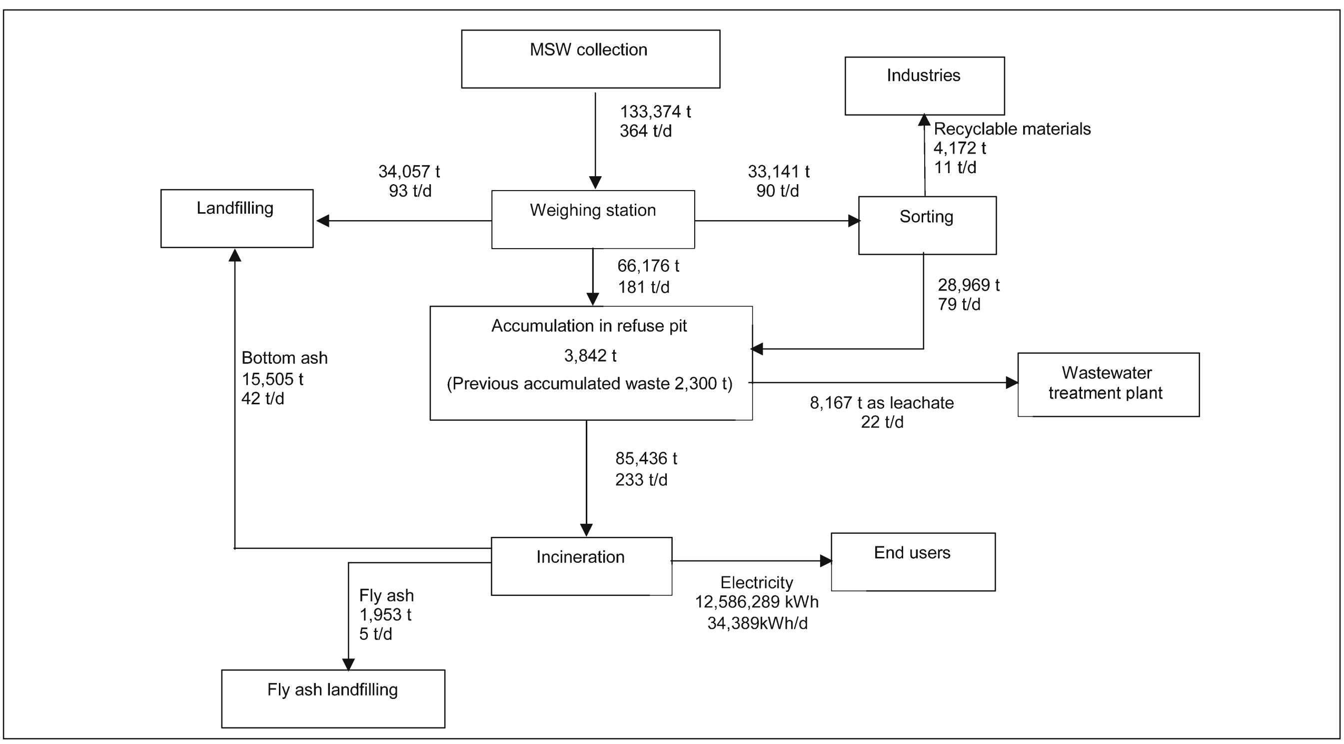

Fig. 1: Current Phuket MSW management system

before transferring to the incinerator is sent to a nearby municipal wastewater treatment plant. Energy is recovered in the form of electricity by steam turbine-generator system, back pressure type, with a capacity of 2.5 MW. Electricity produced by the plant is used within the incineration plant itself, the sorting plant, the wastewater treatment plant and the surplus is sold to the national grid.

There is no power production for Phuket in particular. The electricity using in the Phuket incineration plant is provided by the conventional power plants through the national grid. Information regarding the conventional power production has been provided by Electricity Generating Authority of Thailand [18]. The conventional electricity mix applied in this study is 76.42%, 23.56% and 0.02% from natural gas-, lignite- and oil-fired power plants, respectively.

2 Methodology

Environmental impacts of electricity production from waste incineration are compared with those from conventional power production in Thailand. LCA is used as the evaluation tool. In the following sections each phase of LCA adopted in this study is explained.

2.1 Goal and scope definition

The goal of this study is the comparison of environmental impacts of electricity production from incineration with those of Thai conventional power plants. For the purpose of comparison, a fixed reference point for the environmental evaluation, the functional unit, is defined as 1 MWh net electricity produced (1 MWh_{el}).

The function of the conventional power plants is electricity production whereas the function of incineration is the solid waste management with electricity production as a supplementary function. To make the systems comparable, system boundary of the power plants is expanded to include the alternative process of managing an equivalent amount of solid waste. Landfilling without energy recovery is chosen as the alternative waste management strategy since that is the most commonly used system in Thailand. (In 2003, 64% of MSW was disposed by open dumping and burning, 35% by landfilling and 1% by incineration [19]. There were only 2 landfill sites utilizing landfill gas for electricity production.) Thus, as seen in **Fig. 2**, the comparison is based on the same functions which are (a) electricity production and (b) solid waste management. System boundaries of incineration include waste combustion, leachate treatment and lime and diesel production. Emissions from the power plants used in this study are obtained from the study of the Thailand Environment Institute (TEI) [20]. In the TEI study, the system boundary includes only the power generation process in power plants, i.e. fuel combustion and air pollution control. Extraction, processing and transportation fuels and construction of power plants are not included. However, this is accepted since the conventional power production is used as a baseline for assessment of the environmental impacts from MSW incineration. For the landfilling, the system boundaries include MSW degradation, diesel engine activity in landfill, and diesel production. Based on the existing practice that there is no gas collection and flaring system in Phuket landfill, energy recovery is not included in the consideration. The landfill leachate is assumed to be treated by pond system which is the common method in Thailand. The energy and resource requirements are thus negligible. The main impact from this system would be on land use which is not within the scope of this study.

It is important to note that not all relevant environmental impacts are included in this study due to their insignificance and unavailability of relevant data. For example, ozone depletion is ignored as the considered systems result in insignificant amount of ozone depleting gases. Dioxins in fly ash as well as toxic substances in leachate which pose significant toxicity are excluded in the study due to lack of relevant data.

2.2 Inventory approach

In this phase, emissions of the comparative systems are analyzed and expressed in accordance with the functional unit. The information of emissions from MSW incineration was collected from the actual processes at the study site. Fossil carbon dioxide emitted from incineration system was calculated by using carbon dioxide emission factors for the plastic fraction of waste based on plastic types [21]. Emissions from related activities such as lime and diesel production were derived from the ETH-ESU 1996 database and the BUWAL 300 database. Emissions from the conventional Thai electricity production were obtained from the Thailand Environment Institute [20]. Methane gas from landfill was calculated by multiplying waste fractions with the corresponding emission factors obtained from literature [22]. Emissions from exhaust of diesel engine used for spreading and compaction in landfill were calculated by using emission factors from the BUWAL 250 database.

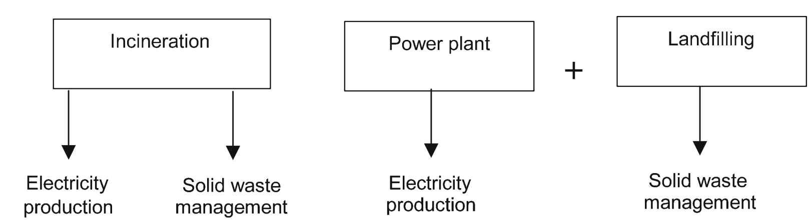

Fig. 2: Comparative systems

2.3 Impact assessment methodology

Potential environmental impacts are calculated based on the data from the inventory analysis. Impact categories considered in the evaluation are global warming (GW), photochemical ozone formation (PO), acidification (AC) and nutrient enrichment (NE). Dioxin emissions and non renewable-resource consumption are discussed.

For impact assessment, the inventory data are classified into the environmental impact categories according to effects they contribute and then characterized. The equivalency factors for GW (over a time horizon of 100 years) are obtained from the Intergovernmental Panel on Climate Change (IPCC) 2001 [23]. Those of PO for low NO_x areas are from [24], AC and NE are from [25].

2.4 Interpretation

Finally, useful results from inventory analysis and impact assessment are discussed in accordance with the goal and scope of the study.

3 Results

Based on the goal and scope, the results of the inventory analysis as well as the impact assessment are presented in this section.

3.1 Inventory analysis

The incineration system itself and related activities – leachate treatment, lime and diesel production as well as electricity production at the power plant – are included in the system boundaries. The major chemical used in air pollution control is lime. Diesel is used for start up of the incineration and as a supplementary energy source. Electricity, from the power plants and incineration plant itself, is used for waste combustion and leachate treatment. It can be seen in Fig. 1 that before the waste is burnt in the incinerator, it is retained in a refuse pit for dewatering. Water going out as leachate is sent to be treated together with municipal wastewater at the wastewater treatment plant (WWTP). Because the WWTP provides two services, leachate treatment and other municipal wastewater treatment, allocation is needed to partition the joint exchanges. To partition the environmental exchanges of leachate treatment from the total exchanges of municipal wastewater treatment, allocation based on BOD loading is used in this analysis. From background calculations, BOD loading of leachate is about 30% of total BOD loading of municipal wastewater. Thus, 30% of the total environmental exchanges (resources and energy used) for the wastewater treatment are allocated to leachate treatment.

Flow diagram of electricity is shown in **Fig. 3**. Of the total electricity consumption for waste combustion, 0.159 MWh/MWh_{el} is from national grid and 1.472 MWh/MWh_{el} from the incineration plant itself. For leachate treatment, 0.064 MWh/MWh_{el} is from national grid and 0.091 MWh/MWh_{el} from the incineration plant after allocating with wastewater from other sources in Phuket municipality. Therefore, electricity consumption for the considered incineration and leachate treatment, enclosed by dashed line, is 1.786 MWh. Electricity produced by incineration system is 2.786 MWh which is used for incineration, leachate treatment, municipal wastewater treatment, sorting, and the surplus sold to the national grid at 1.472, 0.091, 0.124, 0.015 and 1.084 MWh/MWh_{el}, respectively. This amounts to a net electricity production of 1 MWh from the incineration.

For landfilling, MSW having the same composition and amount (19 tons according to the functional unit) as that for the incineration is considered. MSW degradation and related processes, MSW spreading and compaction as well as diesel production, are considered. Energy input is diesel oil which is used in the activity of MSW spreading and compaction. Emissions from landfilling considered in this study are landfill gas, emissions from diesel engine exhaust and emissions from diesel production.

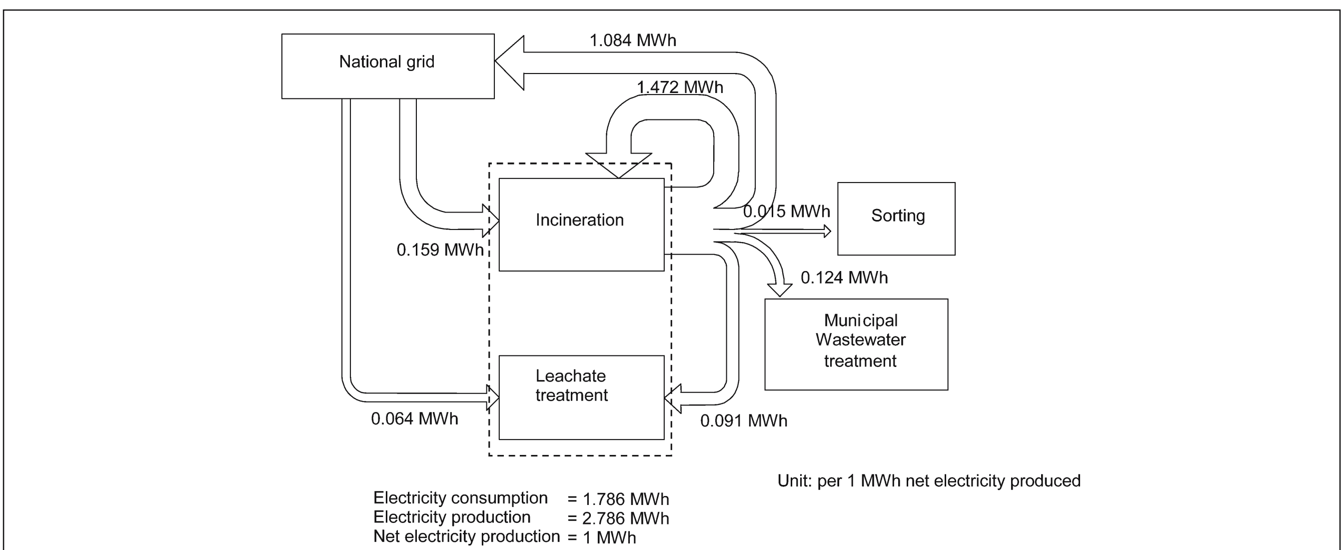

Fig. 3: Flow diagram of electricity

Table 1: Emission comparison of incineration, landfilling and the Thai conventional power plants

Emission	Amount of emission (kg/MWh$_{el}$)					
	Incineration	Landfilling	Conventional power plants			
			Lignite[a]	Oil [a]	Gas [a]	Combined [b]
Fossil CO_2	14,084.946	39.271	1,269.524	812.608	568.878	733.981
CO	11.366	0.198	0.197	0.272	0.197	0.197
N_2O	0.001	0.001	0.040	0.041	0.017	0.022
NO_2	46.662	0.659	5.837	2.858	1.362	2.417
NMVOC	0.298	0.303	0.020	0.047	0.040	0.035
CH_4	0.201	1,077.676	0.015	0.009	0.024	0.022
SO_2	8.742	0.081	2.769	1.282	0.0003	0.653

[a] TEI, 2003
[b] Combined-weighted average of electricity production: 23.56% from lignite-, 0.02% from oil- and 76.42% from gas-fired power plants

Major emissions to air from the incineration and landfilling systems are reported along with the emission intensities of the Thai conventional power plants in **Table 1**.

From Table 1 it can be seen that incineration system produces the highest amount of all emissions except non-methane volatile organic compounds and methane which are produced in the highest amount in the landfilling system. The result of higher level of sulfur dioxide from incineration than that from lignite-fired power plants differs from [15] which indicated that MSW combustion plants emitted lower levels of sulfur oxides than coal-fired power plants. This may due to higher removal efficiency of flue gas desulfurization system of the conventional power plants. With 95% removal efficiency of sulfur dioxide of the flue gas desulfurization system, the conventional power plants emit lower levels of sulfur dioxide.

Detailed analysis of the incineration process revealed that carbon dioxide, carbon monoxide, nitrogen dioxide and sulfur dioxide mainly originated from waste combustion in incineration plant. The relatively small amounts of nitrous oxide and methane originated primarily from the lime production. Volatile organic compounds were produced during coal mining for lime production. From Table 1 it can be seen that a high amount of fossil carbon dioxide is produced. This is because of the high amount of plastic burnt in the incinerator at relatively low efficiency.

For landfilling, methane gas is emitted more than other gases as shown in Table 1. It mainly originates from MSW degradation. Since there is no gas collection and flaring system and with the assumption of 10% methane oxidation in landfill cover [26], 90% of the methane produced is released to the atmosphere. Although carbon dioxide is emitted, it is not considered because, being of biomass origin, it does not contribute to the global warming. Other emissions are mainly produced during combustion of diesel in the engines used for MSW spreading and compaction in landfill.

3.2 Impact assessment

Potential environmental impacts from the MSW incineration system are system shown in **Table 2.**

The combustion process generates high amount of greenhouse gases resulting in high potential impact whereas diesel and lime production have a very small contribution to global warming potential. The major greenhouse gas from combustion is fossil carbon dioxide from burning of a high amount of plastic. The carbon dioxide from the biodegradable waste fractions is not counted because it does not contribute to global warming.

MSW combustion, diesel production and lime production contribute to the impact of photochemical ozone formation. Most of the impact comes from MSW combustion with carbon monoxide as a contributor.

The most significant source of acidification is MSW combustion. However, the magnitude of contribution from this activity is not much because some sulfur dioxide and hydrogen chloride are removed by the air pollution control unit.

All processes of incineration contribute to nutrient enrichment. The most significant source of this impact is MSW combustion with nitrogen dioxide as a contributor.

The weighted average of the potential impacts of lignite, oil and gas fired power plants are shown in **Table 3**. As explained in the scope of the study, for functional equivalence,

Table 3: Potential environmental impacts of Thai conventional power plants and landfilling

Impact potential	Power plants[a]	Landfilling
GWP (kg CO_2 eq./MWh$_{el}$)	741.377	24,826.481
POCP (kg C_2H_4 eq./MWh$_{el}$)	0.022	7.695
ACP (kg SO_2 eq./MWh$_{el}$)	2.345	0.546
NEP (kg NO_3^- eq./MWh$_{el}$)	3.325	0.898

[a] Combined-weighted average of lignite, oil and gas-fired power plants

Table 2: Potential environmental impacts from MSW incineration

Process	GWP (kg CO_2 eq./MWh$_{el}$)	POCP (kg C_2H_4 eq./ MWh$_{el}$)	ACP (kg SO_2 eq./ MWh$_{el}$)	NEP (kg NO_3^- eq./ MWh$_{el}$)
MSW combustion	13,931.012	0.452	43.856	62.794
Leachate treatment	0	0	1.823	5.929
Diesel production	4.518	0.031	0.042	0.037
Lime production	177.015	0.007	0.105	0.205
Total	14,112.545	0.490	45.826	68.965

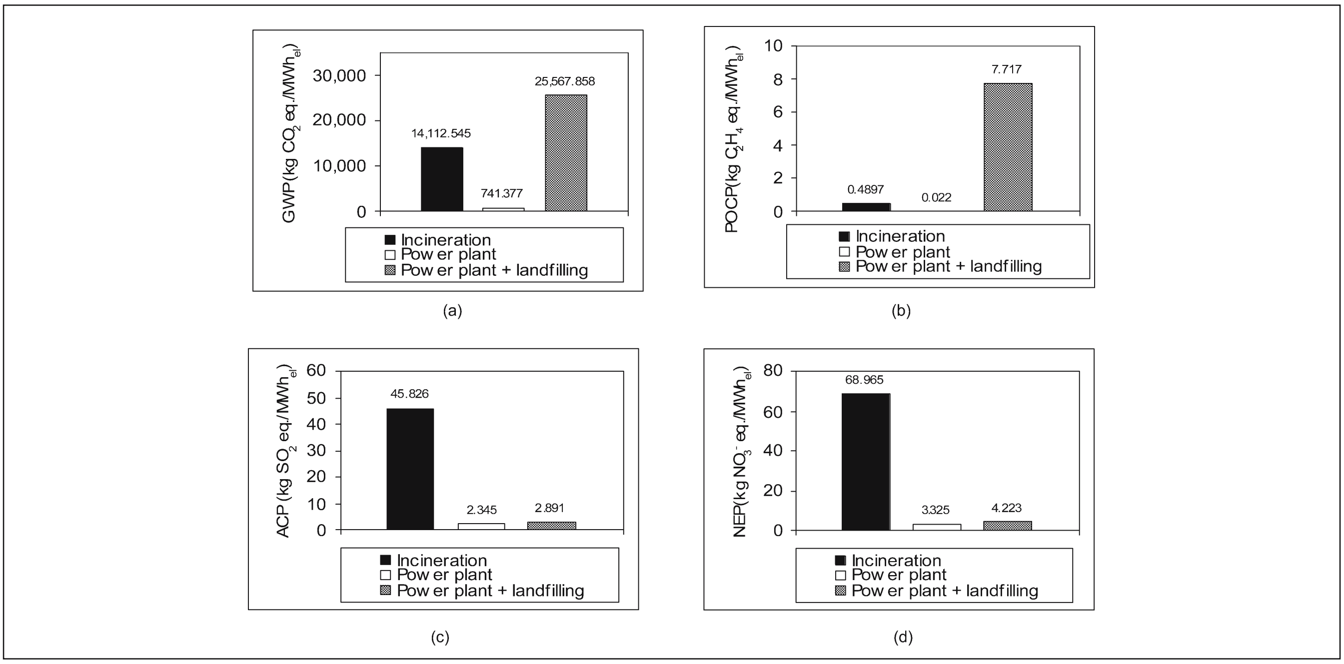

Fig. 4: Potential environmental impacts of comparative systems: (a) global warming (b) photochemical ozone formation (c) acidification (d) nutrient enrichment

the system boundary of conventional power plants has to be expanded to include landfilling. Thus, the potential impacts of the landfilling are also evaluated. The calculation for the impacts from landfilling has been done considering the landfilling of 19 tons of MSW which is the equivalent function provided by the MSW incineration system for producing 1 MWh_{el}. The potential impacts of comparative systems – incineration, power plant, and power plant plus landfilling – are shown in **Fig. 4**.

1) **Global warming.** The incineration contributes to global warming more than conventional power production. This is because high amount of fossil carbon dioxide is generated during MSW combustion. With the inclusion of the landfilling, the power plant becomes inferior because of more global warming contribution as a consequence of methane gas emission from waste degradation. Methane itself has 23 times higher potential to global warming than carbon dioxide thus GWP of the power plant along with landfillling is much more than that of the incineration.

The emission of greenhouse gas from landfilling, which is predominated by methane, might be reduced by introduction of gas collection and flaring systems. If landfill gas is collected and used for energy, a double benefit will accrue because of the reduction in greenhouse gas and also credits from energy conversion. However, this option requires a certain minimum amount of waste to be in place for economic electricity production. In the other case, if the collected gas is flared, methane is converted to carbon dioxide which, being of biomass origin, will not contribute to global warming. However, no additional credits can be obtained in this case.

If 46% of methane gas produced is collected and flared to produce carbon dioxide and 10% of uncollected portion is oxidized in landfill cover, around 48% of the methane gas is emitted to the atmosphere. Then, the GWP of the power plant plus landfilling will roughly be equal to that of the incineration.

2) **Photochemical ozone formation.** The results of comparison are similar to those of global warming. More impact is produced in the incineration as compared with the power plants alone. However, if the landfilling system is included for the evaluation, the potential to produce the impact of methane from waste degradation could turn the result in favor of MSW incineration.

The introduction of gas collection and flaring systems will not change the comparative result in this case. The incineration is still favorable because of much lesser amount of the predominant substance, carbon monoxide, than methane from landfilling.

3) **Acidification.** Incineration system is inferior compared with the power plants since much higher amount of substances contributing to acidification are produced, especially in MSW combustion, than in the power plants. Due to the very low potential contribution this impact, the result of comparison does not change even after landfilling is included with the power plants.

4) **Nutrient enrichment.** The results of comparison are similar to acidification in that the incineration system is inferior compared with the others. In the incineration system, high potential to nutrient enrichment is contributed from nitrogen dioxide in the combustion process. The nutrient enrichment potential of the power plants is rather small, and the addition of impact from landfilling does not change the result of comparison.

5) **Other impact considerations.** Dioxin emissions and nonrenewable resource consumption are very important issues related with waste incineration. Unfortunately, this information is very limited especially for the conventional power

plants in Thailand. Nevertheless, these issues are briefly discussed to give some ideas for further considerations.

Although incineration of MSW is an attractive option for disposal, it has some problems related to the emission of dioxins. Dioxin is the term commonly used to refer both polychlorinated dibenzo-p-dioxins (PCDDs) and poly chlorinated dibenzofurans (PCDFs). Dioxins are types of highly toxic chemicals considered harmful to human health. People exposed to large amount of dioxins experience a skin disease called chloracne. Some studies have shown that high exposures also may contribute to the development of liver, kidney, heart, thyroid and blood disorders, as well as adult onset of diabetes and cancer [27]. Dioxins could be formed as trace by-products in combustion systems like incineration as well as burning of various fuels where chlorine, carbon, hydrogen and oxygen come into contact with heat [28]. Dioxins are an indirect result of incomplete combustion, being formed mainly in the post-combustion zone due to the catalytic reaction of chlorine and products of incomplete combustion on the surface of ash in the temperature range of 250 to 400°C [29].

In this study the information on dioxins from MSW incineration was limited to those from stack emission. Information on dioxins in bottom and fly ash are not available. In the consideration period with 2 times of stack sampling, amount of dioxins from Phuket incineration were 18.63 and 10.48 ng/m^3 TEQ. This is more than an emission limit in Thailand at 0.5 ng/m^3 TEQ for large scale incineration plant at reference condition of 25°C at 1 atm, 7% excess oxygen and dry basis. This may due to presence of chlorinated materials in the MSW to be incinerated. Control of dioxin emissions from incineration may be undertaken by removing chlorinated materials entering the incinerator. In addition to restriction of the chlorinated materials, cleansing of flue gases after dioxin formation could also be considered. The optimal technology proposed by the consulting company at Phuket is adsorption technique using activated carbon powder injection preceding the existing pollution control unit, the bag filter.

Consumption of non-renewable resources is discussed as follows. When electricity generated from incineration is used, the waste is likely to replace natural resources used for conventional production of electricity. In the study, electricity produced at Phuket waste-to-energy incinerator results in the following saved non-renewable resources, i.e. lignite; fuel oil; diesel oil and natural gas, used for Thai conventional electricity production of 1 MWh_{el} at 0.207 tons, 11.717 litres, 0.226 litres and 5,436.986 cu.ft., respectively [16]. The consumption of these natural resources is avoided by using energy recovered from the incineration.

4 Interpretation

The results from holistic comparison between MSW incineration and conventional power production in Thailand show that incineration is advantageous for global warming and photochemical ozone formation but is disadvantageous for the impacts of acidification and nutrient enrichment.

There are some aspects which may influence this result. In the consideration, if the power plants are expanded to included landfill with gas collection and flaring systems, the expanded system could become more favorable than the incineration in the global warming point of view. In addition, details of the evaluation reveal that nitrogen dioxide is a critical factor for acidification and nutrient enrichment. About 74% of acidification potential and all of the nutrient enrichment potential is from nitrogen dioxide. Nitrogen dioxide emissions might be reduced by installation of various types of deNO_x processes, typically either SCR (Selective Catalytic Reduction) or SNCR (Selective Non-Catalytic Reduction). In both processes, ammonia (NH_3) in some form is injected into the flue gas stream where it reacts with the NO_x to form nitrogen (N_2) and water [30–32]. SCR works with a catalyst at lower temperatures (175–500°C) than SNCR (850–950°C) which works without a catalyst. By using SCR, the reduction percentages to be obtained (>90%) are generally higher than with SNCR (<70%) [32]. If 70% of nitrogen dioxide is removed, the potentials of acidification and nutrient enrichment are decreased 50% and 64%, respectively. With this improvement, incineration could become an interesting option for waste management with electricity generation as a bonus.

Conventional power production is superior to MSW incineration on two counts which strongly affect the comparative environmental performance. The first is that the fossil fuels – lignite, fuel oil, diesel oil and natural gas – used for electricity production in the conventional power plants have much higher energy content than MSW to be burnt in the incinerator. Energy content is around 4,231 kcal/kg for lignite, 10,403 kcal/kg for fuel oil, 10,747 kcal/kg for diesel oil and 10,313 kcal/kg for natural gas [16] whereas of the waste is only around 1,750 kcal/kg [33]. To produce the same amount of electricity, high amount of the waste is burnt resulting in high amount of emissions and subsequently high impact potential contribution. Also, moisture content directly affects the energy content with a decrease in energy content of about 5.7 kcal/kg with every percent increase in moisture content. The moisture content of the waste currently going to the incinerator is as high as 40%. The performance of waste in case of heating value will be better if the moisture content can be decreased.

The plant capacity is the other reason in favor of the conventional power plants. The capacities of the conventional power plants range from 858 to 6,370 MW whereas that of the incineration plant is only 2.5 MW. The capacity of the incinerator is thus several orders of magnitude lesser than the fossil-fired power plants which reflects on the efficiency. The energy efficiency of the power plants is around 40% whereas of the incineration plant is only around 7%. It can thus be concluded that incineration, of course, cannot play a role of electricity production as a main function; but electricity production from incineration could be considered as a complement which promotes incineration as a benign waste management option provided appropriate deNO_x and dioxin removal processes are added. A policy promoting incineration should be preferably combined with improvements for effective energy recovery. Due to high moisture content

of the mixed waste and the low energy efficiency of the incineration plant, a separation of high moisture content waste fractions from the waste to be incinerated and an improvement of the operation efficiency of the incineration plant should be pursued.

The results obtained by this study provide valuable information to improve the incineration process. However, further study needs to be carried out to evaluate the toxicity effects of dioxins from both MSW incineration as well as conventional power production in Thailand. Toxicity effects of heavy metals in fly ash and flue gases would also be interesting to evaluate. Even though they have lower impact potentials than dioxins, they contribute to impacts in different environmental compartments. Land-use is another category that needs to be assessed. The assessment of an integrated LCA of MSW management at Phuket including incineration, landfilling and recycling is currently underway.

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References

[1] Gupta AK (2004): Clean Energy Production from Wastes and Plastics. Proceeding Sustainable Energy and Environment, pp 396–408

[2] Leão AL, Tan IH (1998): Potential of Municipal Solid Waste (MSW) as a Source of Energy in São Paulo: Its Impact on CO_2 Balance. Biomass & Bioenerg 14 (1) 83–89

[3] Denison R (1996): Environmental life-cycle comparisons of recycling, landfilling, and incineration: A review of recent studies. Annu Rev Energy Environ 21, 191–237

[4] Finnveden G, Ekvall T (1998): Life cycle assessment as a decision-support tool – The case of recycling vs. incineration of paper. Resour Conserv Recy 24, 235–256

[5] Finnveden G, Johansson J, Lind P, Moberg Å (2000): Life cycle assessments of energy from solid waste. fms 137. FOA-B-00-00622-222-SE, Stockholms universitet, Sweden

[6] ISO (1997): Environmental standard ISO 14040. Environmental management – life cycle assessment – principal and framework. Reference Number: ISO 14040: 1997(E)

[7] UNEP (2003): Environmental management tools: Life cycle assessment. <http://www.uneptie.org/pc/pc/tools/lca.htm>

[8] Gheewala SH (2003): Application of Life Cycle Assessment to Cleaner Production. Int Energ J 4 (1) 5–15

[9] EUROPEAN (1999): Use of Life Cycle Assessment (LCA) as a Policy Tool in the Field of Sustainable Packaging Waste Management. Le Royal Tervuren, Belgium

[10] Doka G, Hischier R (2004): Waste Treatment and Assessment of Long-Term Emissions. Int J LCA 10 (1) 77–34

[11] Bergsdal H, Strømman AH, Hertwich EG (2005): Environmental Assessment of Two Waste Incineration Strategies for Central Norway. Int J LCA 10 (4) 263–272

[12] Chevalier P, Rousseaux P, Benoit V, Benadda B (2003): Environmental assessment of flue gas cleaning processes of municipal solid waste incinerators by means of the life cycle assessment approach. Chem Eng Sci 58, 2053–2064

[13] Mendes RM, Aramaki T, Hanaki K (2004): Comparison of the environmental impact of incineration and landfilling in São Paulo City as determined by LCA. Resour Conserv Recy 41, 47–63

[14] Arena U, Mastellone ML, Perugini F (2003): The environmental performance of alternative solid waste management options: a life cycle assessment study. Chem Eng J 96, 207–222

[15] Ross S, Evans D (2003): The environmental effect of reusing and recycling a plastic-based packaging system. J Clean Prod 11, 561–571

[16] Sonesson U, Björklund A, Carlsson M, Dalemo M (2000): Environmental and economic analysis of management systems for biodegradable waste. Resour Conserv Recy 28, 29–53

[17] Ruth LA (1998): Energy from municipal solid waste: A comparison with coal combustion technology. Prog Energ Combust 24, 545–564

[18] EGAT (Electricity Generating Authority of Thailand). Accessed October 1, 2001 from <http://www.egat.co.th>

[19] PCD (Pollution Control Department, Thailand). Accessed December 22, 2005 from <http://www.pcd.go.th/info_serv/waste_garbage.html>

[20] TEI (2003): Final report for the project on life cycle assessment for Asian countries-Phase III. Thailand Environment Institute, Thailand

[21] Harrison KW, Dumas RD, Barlaz MA (2000): Life-cycle inventory model of municipal solid waste combustion. J Air Waste Manage 50, 993–1003

[22] Sandgren J, Heie A, Sverud T(1996): Utslipp ved håndtering av kommuanalt avfall. Statens forurensningstilsyn (SFT). TA-number 1336/1996. In: Friðriksson GB, Johnsen T, Bjarnasóttir HJ, Slentnes H (2002), Guidelines for the use of LCA in the waste management sector. Nordtest Project nr. 1537-01

[23] Ramaswamy V, Boucher O, Haigh J, Hauglustaine D, Haywood J, Myhre G, Nakajima T, Shi GY, Solomon S (2001): Radiative forcing of climate change. In: Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (eds), Climate change 2001: The scientific basis. Contribution to working group I to the third assessment report of the intergovernmental panel on climate change Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

[24] Andersson-Sköld Y, Grennfelt P, Pleijel K (1992): Photochemical ozone creation potentials: A study of different concepts. J Air Waste Manage 42 (9) 1152–1158. In: Hauschild M, Wenzel H (1998), Environmental Assessment of Products Volume 2: Scientific background. Chapman & Hall, UK

[25] Hauschild M, Wenzel H (1998): Environmental Assessment of Products Volume 2: Scientific background. Chapman&Hall, UK

[26] Climate Leaders (2004): The Climate Leaders Greenhouse Gas Inventory Protocol Core Module Guidance: Direct Emissions from Municipal Solid Waste Landfilling. U.S. Environmental Protection Agency

[27] Unilabs Environmental, Characterisation and Estimation of Dioxin and Furan Emissions from Waste Incineration Facilities. Australia

[28] McKay G (2001): Dioxin characterization, formation and minimization during municipal solid waste (MSW) incineration: review. Chem Eng J 86, 343–368

[29] EPRI (2001):Toxic Release Inventory Chemical Profile: Dioxins. Electric Power Research Institute, USA

[30] Mandel SB, Incollingo M: Calibration Gases for SCR and SNCR Process and Environmental Instrument: Summary. Spectra Gases Inc., USA. Accessed April 26, 2005 from <http://www.netl.doe.gov/publications/proceedings/02/scr-sncr/mandelsummary.pdf>

[31] World Bank, Selective Catalytic Reduction (SCR). Accessed April 26, 2005 from <http://www.worldbank.org/html/fpd/em/power/EA/mitigatn/aqnoscr.stm>

[32] TNO Environment, Energy and Process Innovation, NO_x Emissions Reduced Through Various Technologies. The Netherlands. Accessed April 26, 2005 from <www.mep.tno.nl/Informatiebladen_eng/179e.pdf>

[33] Phuket incineration plant, Operation and maintenance of incineration plant: monthly report, Kumjornkij Construction Company Limited, Thailand

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